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AGRICULTURAL RUNOFF AND RESERVOIR DRAWDOWN EFFECTS ON A 2760-HECTARE RESERVOIR

by

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16. ABSTRACT

The 2760-hectare Big Eau Pleine Reservoir in Marathon County, Wisconsin has experienced frequent winter fish kills and summer algae blooms since its construction in 1937. A study of the reservoir and its 945 square kilometer watershed was conducted from 1974 to 1979 in an attempt to quantify the sources of water quality problems to recommend management practices to reduce these problems. Land use and nutrient loading studies in the watershed identified agricultural runoff, especially animal waste, as the major source of nutrient loading. Total phosphorus loss from the watershed averaged 0.59 kg/ha/yr for the 4-year period; approximately 60 percent occurred during the spring snowmelt and runoff season. Hydrologic and soil erosion modeling indicated that spring snowmelt was the period of greatest runoff and soil erosion and that much of the soil erosion and runoff originates on the lower slopes and alluvial soils.
Recommendations include controlling animal waste spreading during winter and use of conservation practices, especially on lower slopes of the watershed, specifically fencing streams at least 30 feet from the stream channel. Recommended management changes include delaying summer drawdown to minimize internal phosphorus loading, delaying winter drawdown to at least mid-January, and increasing minimum pool volume by 25 percent.

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ABSTRACT

The 2760-hectare Big Eau Pleine Reservoir in Marathon County, Wisconsin, has experienced frequent winter fish kills and summer algae blooms since its construction in 1937. A study of the reservoir and its 945 square kilometer watershed was conducted from 1974 to 1979 in an attempt to quantify the sources of water quality problems to recommend management practices to reduce these problems.

Land use and nutrient loading studies in the watershed identified agricultural runoff, especially animal waste, as the major source of nutrient loading. Total phosphorus loss from the watershed averaged 0.59 kg/ha/yr for the 4-year period; approximately 60 percent occurred during the spring snowmelt and runoff season. Hydrologic and soil erosion modeling indicated that spring snowmelt was the period of greatest runoff and soil erosion and that much of the soil erosion and runoff originates on the lower slopes and alluvial soils.

Reservoir studies indentified Aphanizomenon flos-aquae as the major bloom-producing alga. Summer chlorophyll a values for the four summer periods averaged 105 ug/l and ranged from 65 in 1978 to 120 ug/l in 1976. These yearly variations in chlorophyll a did not correlate with differences in yearly or seasonal total phosphorus loading from external sources. Internal phosphorus loading appeared to be a more important factor in determining summer algae blooms; much of the internal loading is believed to be from drawdown-related resuspension of sediments. Total phosphorus levels in the reservoir begin to increase at about the same time as summer drawdown begins.

Winter oxygen problems in the reservoir were found to be closely related to reservoir drawdown. Sediment oxygen demand, long-term BOD studies, and reservoir monitoring showed that while considerable oxygen would be lost over winter due to biologic reactions, the reservoir would not go anaerobic. Winter drawdown resulted in scouring of sediments high in BOD as the reservoir is gradually drawn down to the old river channel. This scouring causes rapid loss of the remaining oxygen as drawdown moves progressively down the reservoir.

Recommendations include controlling animal-waste spreading during winter and use of conservation practices, especially on lower slopes of the watershed, specifically, fencing streams at least 30 feet from the stream channel. Recommended management changes include delaying summer drawdown to minimize internal phosphorus loading, delaying winter drawdown to at least mid-January, and increasing minimum pool volume by 25 percent.

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SECTION 1

INTRODUCTION

The widespread public interest in water quality has been reinforced by passage of the Federal Water Pollution Control Act, Public Law 92-500, which sets forth the national goal that wherever attainable, navigable waters shall be swimmable and fishable by 1983. Considerable progress is being made in most river systems where the major problem is point sources of pollution. There is less progress on those bodies of water where the primary source of pollutants is non-point, especially where agricultural runoff is involved. An example is the Big Eau Pleine Reservoir in Marathon County, Wisconsin. The reservoir, constructed in 1937, is a 2760-hectare impoundment receiving runoff from a 945-square kilometer watershed in one of the nation's most concentrated dairy centers (Figure 1).

Several studies have identified the reservoir as very eutrophic and pinpointed agricultural runoff as the major source of nutrients (USEPA 1974, Bartelt *et al.* 1973).

In addition to extensive blooms of blue-green algae in summer, the reservoir experiences severe oxygen depletion during winter which causes frequent fish kills. These conditions have aroused widespread public demands that the cause of these problems be determined and corrected. In 1975, 11,000 citizens signed a petition asking the Wisconsin Department of Natural Resources to hold hearings on water-level management, which the petitioners felt was a major cause of the fish kill problems.

The studies summarized in this report were initiated in 1974 in an attempt to identify how sources of nutrients and reservoir management relate to the reservoir's trophic condition and winter oxygen depletion and to recommend ways to alleviate these problems.

Several computer models were chosen to characterize the hydrology and soil erosion characteristics of the watershed relative to its soil types and land use and to quantify the limnological processes occurring in the reservoir. An initial goal was to integrate the various programs into a single model that could be used as a management tool, but the state of the

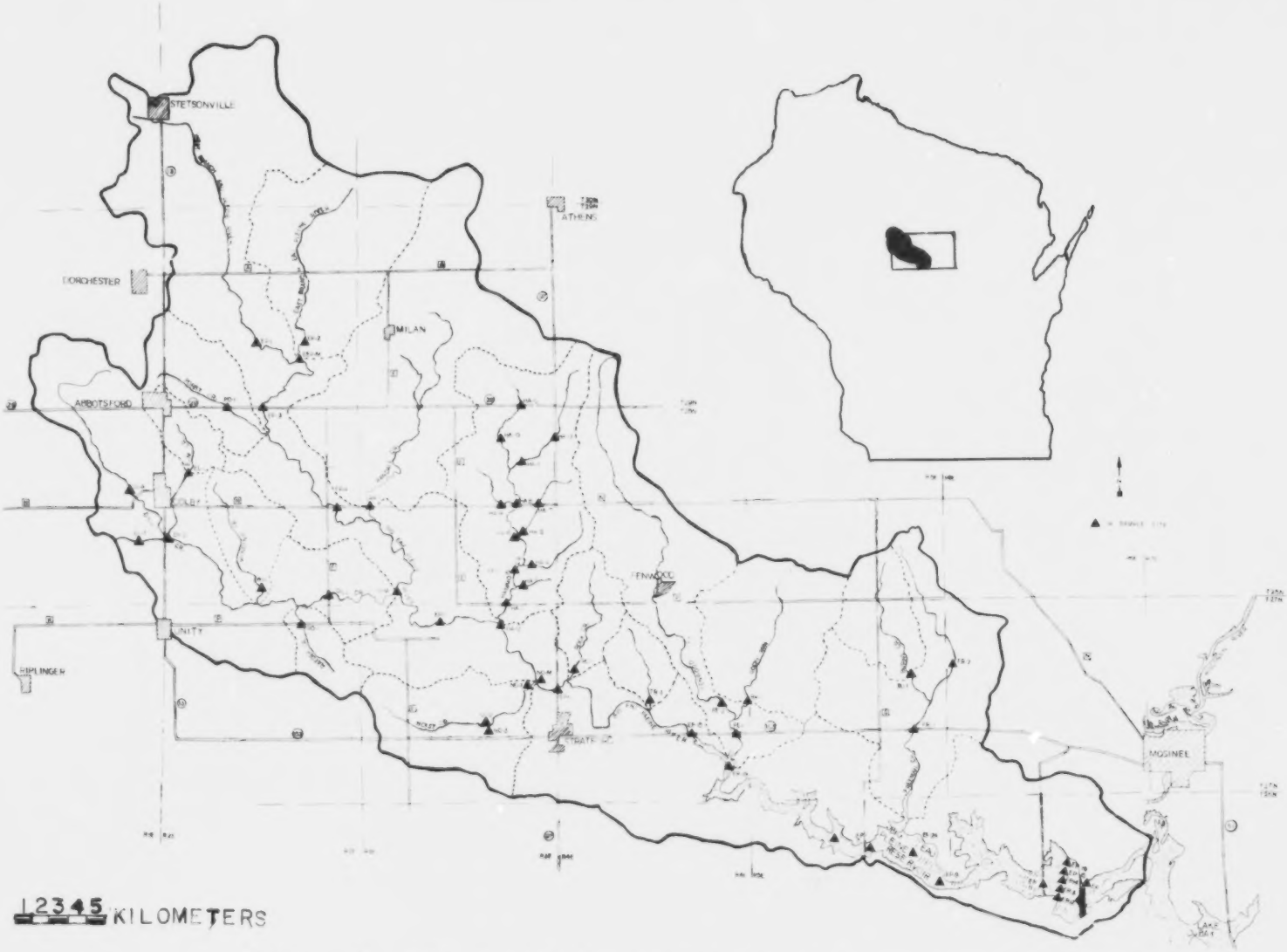

Figure 1. Big Eau Pleine Watershed, Marathon County, Wisconsin

art of existing computer programs prevented the achievement of this goal. Each model output has been used separately in developing the conclusions and recommendations in this report.

The use of computer models for an area the size of the Big Eau Pleine Watershed and Reservoir requires an intensive data base and models that can simulate diverse conditions. This is particularly true of the hydrology and soil erosion models; they required considerable modification to work with data from a watershed with diverse soils and land-use conditions. The reservoir water quality model caused the most problems since it could not simulate a mass balance during drawdown period. However, the model did help identify and quantify some of the major nutrient exchange processes between the reservoir and its sediments and nitrogen fixation by algae.

SECTION 2

CONCLUSIONS

The water quality problems in the Big Eau Pleine Reservoir are due both to land-use activities in the watershed and to reservoir management. The main cause of high nutrient loading to the reservoir is agricultural-related activities in a watershed where seasonal surface runoff is high. Family-owned dairy farms account for over 90 percent of the land in the watershed; winter spreading of manure and cattle grazing up to and often through the stream channel is very common. These sources of animal wastes, along with fertile soils that have slow infiltration rates, result in high nutrient losses to the drainage.

The heaviest nutrient loss from the watershed occurs during snowmelt and spring rains which coincide with the reservoir refill after winter drawdown. Approximately 60-70 percent of the annual total phosphorus load enters the reservoir during March and April.

The spring runoff creates initially high total phosphorus levels in the reservoir (0.2 mg/l) which stimulates an early bloom of diatoms and green algae. The phosphorus concentration, however, decreases rapidly due to sedimentation and algae uptake and only begins to increase again when water levels are lowered. Phosphorus is released from the sediments by wind agitation when sediments are exposed during drawdown and, to a lesser extent, from anaerobic sediment release. This increases total phosphorus concentrations throughout the drawdown period which, in turn, support exceptionally large blooms of Aphanizomenon flos-aquae.

However, winter oxygen depletion in the reservoir and subsequent fish kills are the major water quality concern. Oxygen depletion proceeds from the bottom upward, as is common in eutrophic lakes. This process alone would not cause anaerobic conditions throughout the entire reservoir. However, as reservoir drawdown proceeds, the upstream portions of the reservoir are converted to a river condition resulting in resuspension of sediments that have accumulated in the deeper water during spring runoff events and summer algae production. These sediments, being anaerobic and high in organic matter and reduced iron and sulfur, remove any remaining oxygen in the

water they contact. As this problem moves downstream, the remaining oxygen is gradually removed as drawdown and sediment resuspension continue. During winters with high tributary flows and delayed drawdowns oxygen depletion is less severe.

Computer models used in this project were generally helpful in quantifying environmental processes and in identifying major factors to consider in solving the watershed and reservoir problems. However, all of the models used need further refinement; ideally they should be integrated for a more useful management and research tool.

SECTION 3

RECOMMENDATIONS

The solutions to the problems in the Big Eau Pleine Reservoir are expensive and complex. Recommendations fall into two categories--Land Use and Reservoir Management.

A. Land Use

1. Overwinter manure storage should be provided on each farm and manure applied to the land should be incorporated into the soil without delay.

2. Stream channels should be fenced to exclude livestock, except at carefully selected watering sites. A minimum of nine meters of buffer strip should be left on each side of the channel.

3. Soil conservation plans should be implemented on each farm to reduce soil erosion and associated nutrient loss.

4. Small runoff-retention ponds should be encouraged to act as sediment and nutrient traps, resulting in higher base flow levels in the river through increased ground-water recharge.

5. Land disposal of cheese factory wastes should be handled the same as farm manure. Overloading soils should be avoided as the wastes are very high in nitrogen and phosphorus. Lagoon storage and summer spreading would prevent much of the current nutrient loss.

B. Reservoir Management

Even if all of the above land-use recommendations were to be followed, serious water quality problems in the Big Eau Pleine Reservoir are likely both in summer and in winter. The following guidelines could be used to manage the reservoir to alleviate existing problems and those that will persist even after land-use practices have improved.

1. Summer nutrient levels and resulting algae blooms could be reduced:

   a. If early spring runoff, which has the highest phosphorus levels, were allowed to flow through the reservoir before refilling is started, this would reduce the amount of phosphorus retained in the reservoir for use by algae later in the year. This practice would only be feasible if a large snow pack existed.

   b. If, as this study has shown, resuspension of sediment phosphorus is a significant source for summer algae blooms, it would be desirable to hold the reservoir at as constant a level as possible and use short periods of more rapid drawdown instead of a steady, slow drawdown.

2. Winter oxygen problems could be minimized by:

   a. Allowing the reservoir to fill as much as possible during the fall prior to freeze-up.

   b. Delaying any winter drawdown until at least mid-January.

   c. Stopping drawdown when the reservoir volume is reduced to 25% of the full volume.

If the above recommendations are not feasible due to economic or political reasons, it may be possible to prevent winter fish kills by using mechanical aeration; however, even with aeration, a modified drawdown may be necessary.

SECTION 4

MATERIALS AND METHODS

To develop data needed for the various land-use and water-quality aspects of this study, an extensive sampling and analysis program was initiated in May 1974 (sampling sites are shown in Figure 1). Bi-weekly samples were collected from all reservoir sites and Fenwood, Freeman, and Hamann creeks through 1978. Monthly samples were collected from all other tributaries through 1977. An automatic sampler was installed at site EP-6, near Stratford, in the spring of 1976, and samples were collected there four times daily through 1979.

Analyses of water samples were performed in the Environmental Task Force Laboratory at the University of Wisconsin-Stevens Point. All methodology was consistent with the 14th edition of Standard Methods (APHA 1975).

Water quality parameters and methods of analysis used in this study were:

Reservoir--Field measurements - temperature, dissolved oxygen, Secchi disc, and ice and snow thickness. Lab analyses - BOD_5; chlorophyll, Kjeldahl, ammonium, and nitrate plus nitrate nitrogen; total and reactive phosphorus; total and volitile suspended solids; conductivity; hardness; alkalinity; and pH.

Tributaries--Field measurements - temperature, dissolved oxygen, and periodic flow. Lab analyses - same as for reservoir samples.

Automatic sampler--total and reactive phosphorus; conductivity; Kjeldahl, ammonium, and nitrate plus nitrate nitrogen; chlorides; and total and volatile suspended solids.

Primary production was measured by in situ incubations from May 1975 to January 1977 using oxygen and carbon-14 methods (Sullivan 1978).

Phytoplankton biomass was determined by direct enumeration using a Palmer counting chamber with samples concentrated by sedimentation.

Sediment oxygen demand (SOD) was determined using an *in situ* chamber and dissolved oxygen probe and recorder and by using an environmental chamber at 20° and 4°C. Dissolved oxygen was measured every few hours with a Weston-Stack dissolved oxygen meter to obtain oxygen depletion rates (Hammermeister 1980).

Climatic data used in the computer models were obtained from the National Oceanographic and Atmospheric Administration. Hourly rainfall, temperature, wind speed, dew point, and cloud cover data were obtained for the Wausau WIFAA Airport site. Hourly precipitation data were obtained for the Big Eau Pleine Dam, Marshfield and Medford, and Wausau 7SSW stations.

Flow data were obtained for site EP-6 near Stratford from the U.S. Geological Survey (USGS). This site on the Big Eau Pleine River is a continuous flow-monitoring station. The drainage area above this site is 580 kilometers^2 or about 65% of the total watershed. Suspended solids data collected over a 15-year period by USGS were used in calibrating the soil-erosion model.

All water quality, climatic, and flow data were coded, keypunched, and loaded onto disk files for a Burroughs 6700 computer system. Data analysis was done by a series of specially designed computer programs (Vennie 1981). "Minilab" (Ryan *et al.* 1976) and "SPSS" (Nie *et al.* 1975) were the major data-handling and statistical computer systems.

Land-use data were generated by two methods. The first was to determine land use and soil conservation needs for the entire watershed; the second was to obtain detailed data for each farm in the Hamann Creek Watershed for use in the Hydrology and Soil Erosion models.

Land use and soil loss were determined for each field in 42 quarter sections (2.8% of the land) randomly selected within the Big Eau Pleine Watershed. Field investigations were conducted on each field in the sample area to obtain values for each factor in the Universal Soil Loss Equation (Wischmeier and Smith 1965). Fields were subdivided wherever significant soil or slope changes occurred. Farmers were interviewed to obtain data on crop rotation, crop residue management, timing of tillage, and existing conservation practices.

These data were entered in a computer program for land use, land treatment, sedimentation, and erosion (U.S. Department of Agriculture-Soil Conservation Service 1975). This program was modified to include additional conservation practices for use in calculating alternate ways to bring a field within soil-loss tolerances (Hansen 1979).

Land-use data for the Hamann Creek Watershed were collected by a combination of mail questionnaires and interviews with farmers. Soil type, topography, and current land use were determined by using Soil Conservation Service soil maps, U.S. Geological Survey topographic maps, and aerial photography. Land-use data were subdivided for each sub-watershed of the Hamann Creek basin and for three hydrologic zones in each sub-basin. These data were then used in the USDAHL 74 modified model of watershed hydrology (USDA 1975) and the soil erosion model, "ACTMO" (Frere et al. 1975).

SECTION 5

STUDY AREA

The Big Eau Pleine Watershed has a drainage area of 945 square kilometers, most of which is in Marathon County; small parts of the upper basin are in Clark and Taylor Counties (Figure 1).

The Big Eau Pleine Watershed is composed of 12 individually-named basins ranging in size from 8.5 to 159 square kilometers. A continuous-recording stream gauging station is located on the Big Eau Pleine River 5 meters upstream from the State Highway 97 bridge near the Village of Stratford. The area of the watershed above this site is 580 square kilometers.

The watershed is characterized by a temperate continental climate with average January and July temperatures of -10 and 21 degrees Centigrade, respectively. Average annual precipitation is 81.3 centimeters. Heaviest precipitation occurs during May and June. Snowfall depth averages 132 centimeters.

The average date of the last killing frost is May 19, and the first killing frost is September 23--a 126-day average growing season.

The bedrock geology of the area is predominantly granite and undifferentiated igneous and metamorphic rocks. Depth to bedrock is generally not much greater than 1.5-2.4 meters (Hole 1976).

The topography of the area is characteristic of a peneplain. The watershed was not influenced by the last glacial advance, but portions obviously were glaciated during an earlier advance which left thin ground moraines over bedrock.

Most soils in the watershed have silt-loam surface textures. This silty material, from wind-blown loess, overlies acid sandy-loam to clay-loam glacial till or fine textured residual soils. The dominant soil series on the uplands are the Withee, Fenwood, Marathon, and Rozellville--all Typic Glossoboralfs. The Marshfield soil series (Typic Glossoboralf) is dominant on the concave slope positions, and the Mann soil series (Typic Haplaquoll) is the major soil found in depressions and lower slope positions.

The bedrock geology, together with fine textured glacial deposits and surface soils, has resulted in a watershed that does not absorb water quickly. The well-developed dentritic drainage pattern, combined with soil of low permeability, results in rapid increases in stream flow during precipitation events (Figure 3). The large amount of runoff, along with shallow dense bedrock material, results in a minimal amount of ground water storage and, therefore, very low base-flow conditions. Gauged flows in the Big Eau Pleine River at Stratford have ranged from zero to 1,160 cubic meters per second (USGS 1978).

In 1907 the Wisconsin Valley Improvement Company (WVIC) was formed to build reservoirs on the Wisconsin River system to stabilize flows. This led to the construction of the Big Eau Pleine Reservoir in 1937 to provide water for maintaining a minimum flow in the mid and lower Wisconsin River for hydro power production. Because of this, the reservoir undergoes wide fluctuations in water level (up to 9 meters) on an annual basis. Physical and limnological data of the Big Eau Pleine Reservoir are summarized in Table 1.

TABLE 1. PHYSICAL AND LIMNOLOGICAL DATA OF THE BIG EAU PLEINE RESERVOIR.

*Surface Area	27.6 km^2	+Shorline	106.2 km
*Max Volume	131.5 x $10^6 m^3$	*Watershed Area	945.4 km^2
Min Volume	1.72 x $10^6 m^3$		
*Mean Depth	4.8 m	*Mean Detention Time	0.4 yr.
+Length	24.8 km		
+Width	4.5 km	Total Alkalinity (mg $CaCO_3$/l)	17-35

*(U.S. EPA 1974)
+At maximum volume

Water quality problems in the reservoir were first noticed shortly after construction and periodic winter fish kills have occurred since then. The reservoir is popular with area sportsmen who find fishing excellent during years when sensitive fish kills do not occur. This is demonstrated by the fact that over 11,000 signatures were obtained in 1974 from sportsmen request-

ing a hearing into water level management by the WVIC. The conflict between water use for recreation and low-flow augmentation on the Wisconsin River still exists and hopefully will be partly settled as a result of this study.

SECTION 6

RESULTS AND DISCUSSION

WATERSHED STUDIES

Watershed - land-use studies involved the following three components:

1. A land-use survey of 2.8 percent of the total watershed area and use of the universal soil loss equation to determine conservation needs on each field in this sample (Hansen 1978).

2. A hydrologic modeling project to relate hydrologic characteristic of sub-basins in Hamann Creek to nutrient loss and land use (Elbert 1979).

3. A soil erosion modeling project to relate sediment and its associable nutrient loss to land use and watershed characteristics in the Hamann Creek watershed (Kaminski 1977).

Land Use Survey

The results of the land use - soil erosion inventory as reported by Hansen (1978) are summarized in Table 2.

It is obvious from these data that, on the average, soil loss in the Big Eau Pleine Watershed is not high (4.82 M. tons/ha); however, approximately 25 percent of the land area exceeds the "allowable soil loss." The data also indicate that 95 percent of the soil erosion occurs on cropland; pastured areas account for about 5 percent of the total.

Cost estimates of controlling soil erosion were based on conservation practices recommended in 13 recent farm plans prepared by the Soil Conservation Service. This information is summarized in Tables 3 and 4.

TABLE 2. LAND USE AND SOIL EROSION IN THE BIG EAU PLEINE RESERVOIR FROM THE 2.8 PERCENT LAND USE SURVEY USING RAINFALL FACTORS (R) OF 125-150 and 184

Land Use	Hectares	Erosion M. Tons/yr R=125-150	Erosion M. Tons/Ha R=125-150	Erosion M. Tons/yr R=184	Erosion M. Tons/Ha R=184
Cropland	54,527	288,060	5.28	420,031	7.70
Woodland	15,944	1,995	0.13	2,993	0.19
Pasture	13,582	13,060	0.96	19,228	1.42
Other	7,677	--	--	--	--
Total or $\bar{x}$	91,730	303,115	3.30	442,252	4.82
% of Total Area Exceeding Allowable Soil Loss*			15		25

*Allowable soil loss for all soils in the watershed is 6.75 metric tons/ha (2.72 tons/acre).

TABLE 3. ESTIMATES OF COST FOR CONTROLLING SOIL EROSION ON 618 HECTARES OF CROPLAND ON 13 FARMS IN THE BIG EAU PLEINE WATERSHED.

Practice Needed	Amount Needed	Price per Unit	Total Cost
Contour Strips	194 Ha	$9.90	1,920
Grassed Waterway	24,785 Meters	1.48	36,682
Diversions	37,581 Meters	1.31	49,231
Terraces	6,977 Meters	1.15	8,023
Cost per Ha $155.11			95,856

TABLE 4. ESTIMATES OF COST FOR VARIOUS LEVELS OF SOIL CONSERVATION PRACTICES IN THE BIG EAU PLEINE WATERSHED.

Area to be Treated	Cost per Ha	Total Cost Estimate (Rounded)	Basis for Treatment
14,928 ha	$155.14	$2,300,000	Areas exceeding 6.7 tons/ha soil loss using rainfall factor 125-150
23,587 ha	155.14	3,700,000	Areas exceeding 6.7 tons/ha soil loss using rainfall factor 184
55,315 ha	155.14	8,500,000	All cropland

It is obvious from these estimates that conservation practices required to reduce soil erosion to the soil loss tolerance level are very expensive. The practices included in this analysis do not include a number of high cost practices that would be desirable to reduce nutrient loss, such as manure storage facilities and stream fencing. Use of these practices would at least double the estimated costs in Table 4.

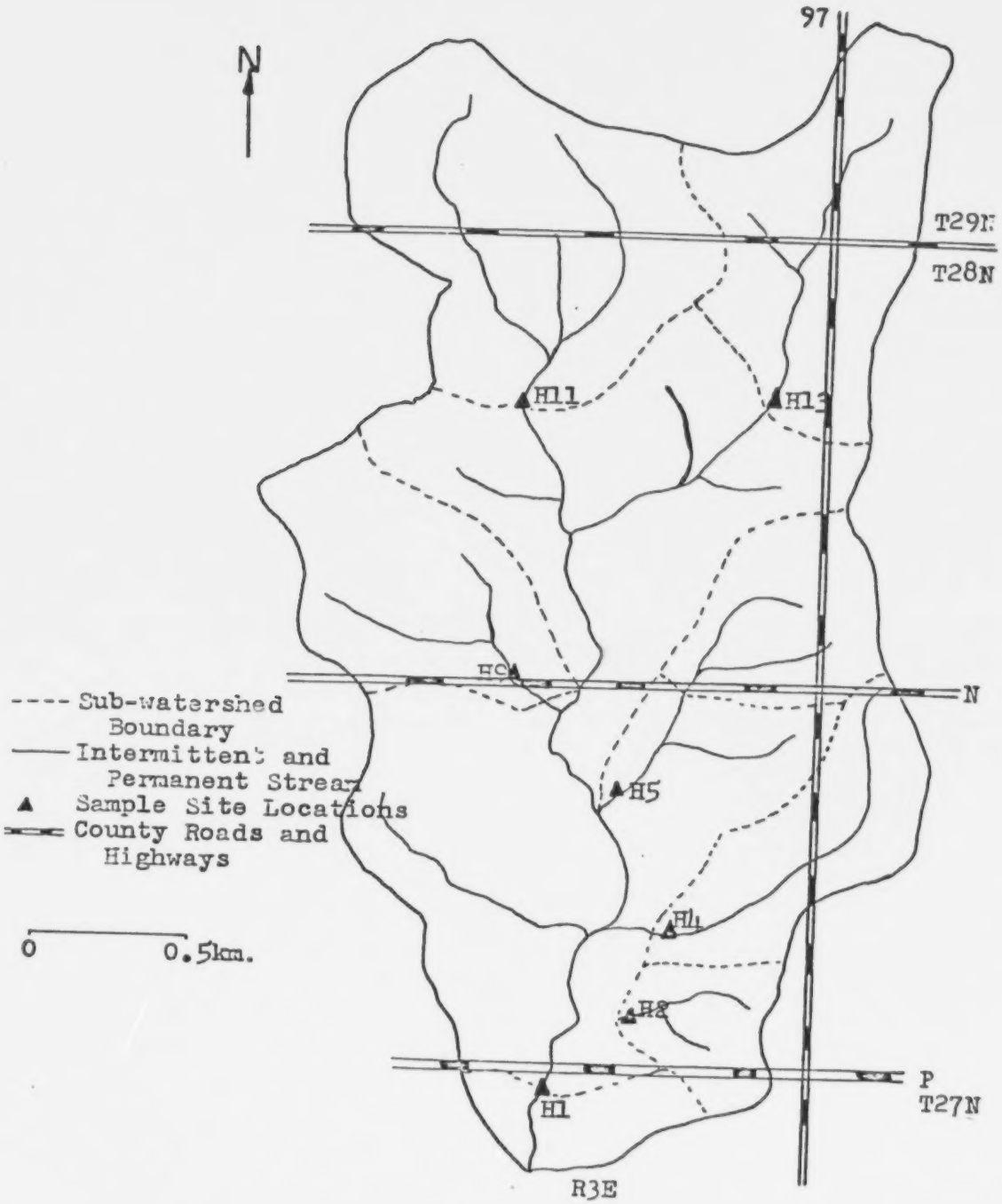

Figure 2. Sample site location and subwatershed boundaries of the Hamann Creek Watershed.

Hydrologic Modeling

Hydrologic modeling of the Big Eau Pleine Watershed and the Hamann Creek sub-watershed was undertaken to help determine sources of nutrient and suspended solids loadings and to provide recommendations for "Best Management Practices" to reduce this loading. The USDAHL-74 computer program (USDA 1975) was calibrated using flow records from the Big Eau Pleine River at Stratford and then applied to the Hamann Creek sub-watershed. A detailed land-use inventory was obtained for each of 8 sub-basins and each hydrologic zone in the Hamann Creek Watershed for use in the model and to draw correlations between land-use, hydrologic response, and nutrient loading to streams. Figure 2 shows the watershed, its sub-basins, and sample sites used for water quality analysis. Table 5 summarizes the land-use data by hydrologic zone for Hamann Creek and for the Big Eau Pleine Watershed based on the 2.8% survey.

The hydrologic model, while requiring considerable effort and computer time, accurately simulated flows in the Big Eau Pleine River (Figure 3). The only weakness in the model appears to be in the snowmelt routine which is not sufficiently well-developed to generate precise flow estimates during this critical time of year. Marano (1979) tested several snowmelt models on the Big Eau Pleine Basin and found that the NPS model of Donigan and Crawford (1976) provided the most accurate simulation.

TABLE 5. LAND-USE DATA BY HYDROLOGIC ZONE INCLUDING HECTARES OF ALL CROPS FOR THE HAMANN CREEK SUB-BASIN AND FOR THE 2.8% LAND USE SURVEY OF THE BIG EAU PLEINE WATERSHED.

Zone	Corn	Oats	Hay	Pasture	Forest	Idle	Residential Roads	Total
I	741.2	775.2	1610.2	974.2	102.4	121.8	96.0	4421.0
II	147.9	132.7	283.4	803.8	106.9	10.5	152.6	1637.8
III	3.0	2.8	11.9	332.6	15.3	1.3	23.0	389.9
Sub total	892.1	910.7	1905.5	2110.6	224.6	133.6	271.6	6448.7
% of Total	13.8	14.1	29.5	22.3	14.0	2.1	4.2	100
% Based on 2.8% Inventory of the Entire Watershed	12.5	14.0	32.8	14.9	(17.4)		8.4	100

The output of the hydrology model indicated that approximately 50 percent of stream flow originates from overland flow and that much of the overland flow originates in the alluvial areas.

Runoff from the alluvial soils (zone III) made up as much as 90 percent of the total return flow during the snowmelt and spring rain period. These data indicate the importance of considering land uses on the lower slopes when attempting to reduce nutrient or sediment loss.

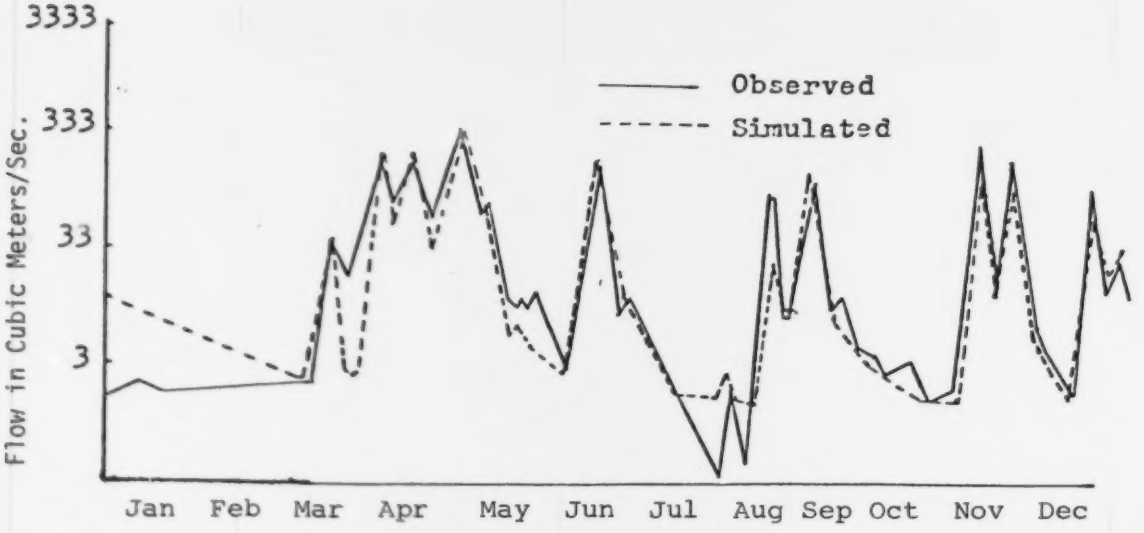

Figure 3. Big Eau Pleine River hydrograph and simulated hydrograph for 1975 at Stratford.

This does not indicate that alluvial soils are the greatest problem but only that they should be managed carefully where they do exist, as they are the wetter areas ajacent to waterways and have a high probability of generating surface runoff that could carry nutrients and sediment.

While alluvial soils generate a large percent of total flow as overland flow, sub-basins with high percentages of alluvial soils produce a lower percent of their total discharge as overland flow than those with small amounts of alluvial soils.

Table 6 summarizes the nutrient and hydrologic computer output for Noisy and Hamann Creek tributaries and lists the zone III land-use characteristics and animal densities for these tributaries. These data do not indicate any striking relationships between land use and nutrient loss since land use was fairly uniform between sub-basins. They do, however,

show that nutrient loss from all sub-basins is quite high. No individual sub-basin had any significant number of conservation practices in place, making it difficult to estimate to what extent nutrient loading could be reduced by implementing such practices. The fact that approximately 65 percent of the annual nutrient loading and the highest nutrient, suspended solids, and fecal coliform counts occur during the snowmelt and spring rain period, indicates that winter spreading of manure is a major source of nutrient loss in this area. Summer nutrient losses were most closely correlated to percent of zone III pastured (Elbert 1979) indicating again that animal wastes deposited near stream areas are an important source of nutrient loading.

TABLE 6. COMPARISONS OF N AND P LOSSES TO OVERLAND FLOW VOLUMES, RETURN FLOW VOLUMES, ANIMAL DENSITIES, AND PERCENT ZONE III PASTURED AND CULTIVATED FOR HAMANN AND NOISY CREEK TRIBUTARIES 1975 & 1976.

Basin	Nitrogen Kg/ha 75	76	Phosphorus Kg/ha 75	76	Overland Flow (cm) 75	76	Return Flow (cm) 75	76	% of area in zone III 75-76	% of zone III Pastured 75-76	Cultivated 75-76	Animal Density (NO./ha) 75	76
H-1	3.90	11.19	.298	.553	13.16	13.44	10.87	10.13	6.2	85.5	0.1	.17	.17
N-1	3.40	6.65	.376	.430	12.32	8.28	13.87	14.10	9.0	50.5	4.0	.19	.19
H-2	5.15	10.16	.372	.412	15.60	15.11	9.27	7.77	5.9	97.0	3.0	.27	.27
H-4	5.15	10.94	.403	.685	10.92	6.27	17.40	19.00	13.1	24.5	0.0	.14	.15
H-5	4.07	4.93	.900	.286	17.68	13.08	7.59	7.19	2.0	69.9	8.5	.21	.20
H-9	4.67	7.29	.494	.617	11.58	10.41	12.73	13.08	9.3	85.3	0.0	.25	.26
H-11	4.13	5.61	.242	.334	13.82	14.38	8.38	7.37	3.9	74.0	4.9	.17	.16
H-13	3.25	5.62	.389	.330	14.63	14.38	9.04	8.15	3.0	65.0	0.0	.18	.18
Means	4.22	7.80	.434	.456	13.74	11.92	11.14	10.85	6.6	68.9	2.6	.20	.20

Soil Erosion Modeling

Soil erosion modeling was included in this study to help identify sources and amounts of soil loss and the nutrients associated with soil loss. The model selected was the erosion submodel of ACTMO (Agricultural Chemical Transport Model, Frere et al. 1975). This model had to be modified for application in a watershed with the diversified land use found in the Big Eau Pleine.

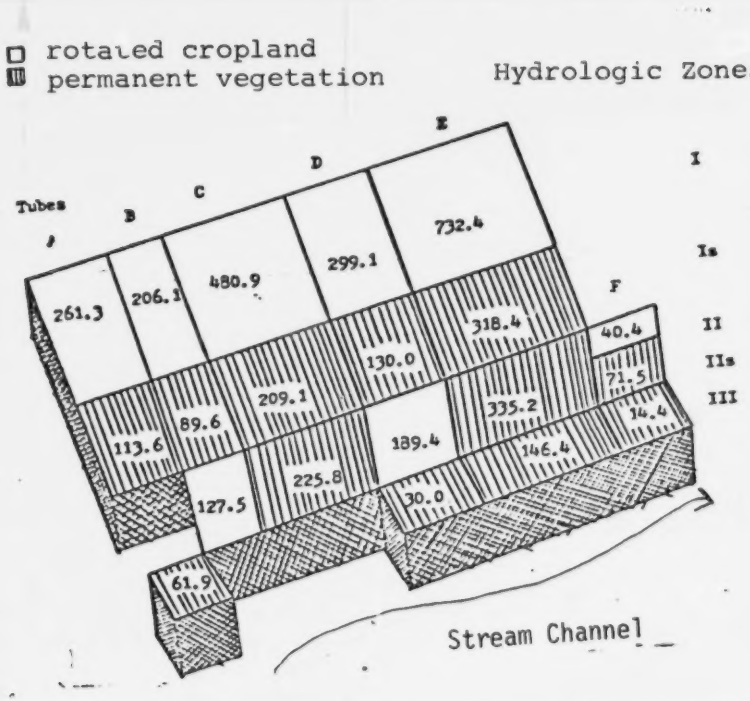

Figure 4. Computational unit (tubes for the Hamann Creek Watershed as used in the erosion model).

Figure 4 shows the way the watershed was subdivided into tubes to route flows through various land uses in different hydrologic zones. The same hydrologic zones were used as in the hydrologic modeling work. Designation of a tube amounted to splitting land use in each zone into cultivated and uncultivated percentages to allow more realistic simulation of water routing than the original model which accommodated only one land-use category per watershed. This resulted in the 6 tubes shown in Figure 4. Soil loss per tube averaged over eight summer storms in 1974 and 1975 was:

Tube	A	B	C	D	E	F
Soil loss/Storm (kg/ha)	1.7	5.7	2.8	1.4	2.3	.2

These model data indicate that the highest soil loss to the stream occurs where cultivated fields are adjacent to a stream, as in Tube B, and that the lowest soil loss occurs where there is a large area of permanent vegetation between cultivated fields and the receiving streams. These results lend support to the concept of using buffer strips along stream channels to help reduce sediment and associated nutrient loss. This would be most beneficial if such areas were not grazed;

the soil would be less dense and permit greater infiltration of water.

Results from this study indicated the following problems with current use of the Universal Soil Loss Equation (Wischmeier and Smith 1965).

There is only one K value, or soil erodibility factor, used per soil series. This does not allow the equation to account for differences in soil roughness or permeability. This means that the same soil loss is calculated for a site if it is grazed or ungrazed and does not account for the effect of vegetation on slowing water movement, affecting soil permeability, frost depth, or snow accumulations, all of which can significantly affect soil erosion and would be important in evaluating land-use alternatives for erosion control. The use of a separate conveyance factor has been suggested to overcome this problem (Piest et al. 1975, Kaminski 1977). Initial simulations involving erosion during snowmelt and early spring rain events greatly underestimated observed soil loss. The K factor, when increased from 0.43 to 0.65, resulted in accurate simulations. The effect of frozen or very wet soil on erodibility had been noted by other researchers (Bubenzer and Mitchell 1977, Hewlett and Nutter 1969, Hudson 1971, Klausner et al. 1976, Skidmore et al. 1975).

The rainfall factor (R) used in the Universal Soil Loss Equation is based primarily on average annual rainfall amount and intensity during summer. This would give a zero R during the snowmelt period of March and April. Figure 5 illustrates the actual distribution of soil loss to the Big Eau Pleine and Hay rivers over a 15-year period. These data indicate that the current R value of 125 to 150 used for the Big Eau Pleine Watershed should be increased to account for soil erosion during the snowmelt period.

Kaminski (1977) calculated a spring R value of 39 based on nine snowmelt and spring rain simulations in the Big Eau Pleine Watershed. When this value is added to the current values for R used in this area (125 and 150), new yearly R values of 164 and 189 are obtained. As seen in Table 2, use of an R value of 184 increased the area exceeding soil loss tolerance from 15% to 25% of the Big Eau Pleine Watershed.

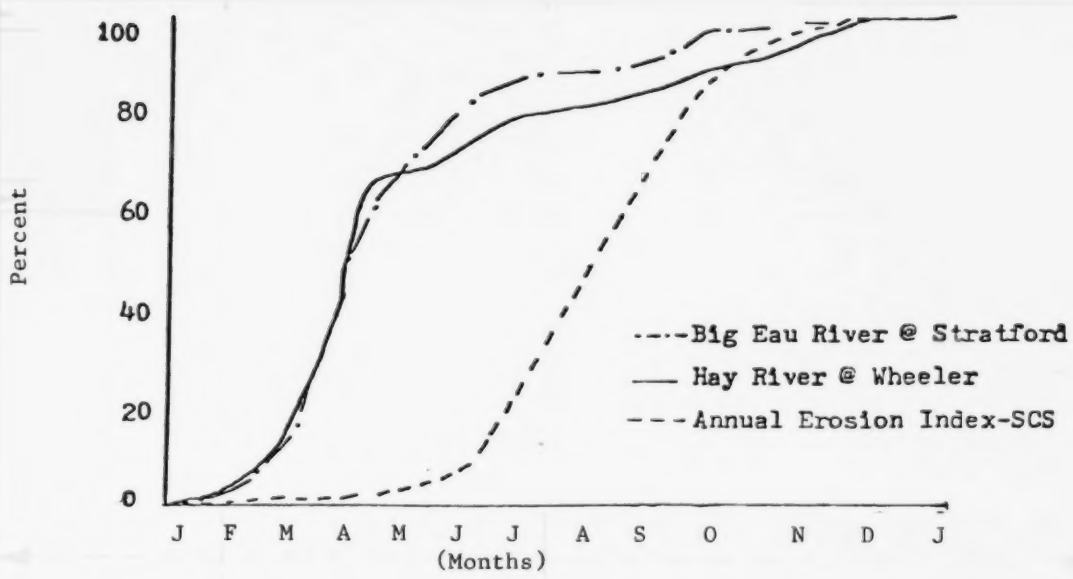

Figure 5. Distribution of annual sediment load in the Big Eau Pleine and Hay Rivers over a 15-year period compared to SCS annual erosion index.

RESERVOIR NUTRIENT BUDGET

The relationship between snowmelt and rainfall induced runoff and nutrient and BOD loading to the Big Eau Pleine Reservoir is shown in Table 7. The discharge of water and associated nutrients and BOD on a monthly basis is also shown. These data, which include all tributary and precipitation inputs, clearly show the month-to-month and yearly variability that occurs in this watershed. This indicates that even four years of data may not be sufficient to characterize the nutrient loading of a watershed that is heavily influenced by surface runoff. Outflow data are also shown to vary considerably from month to month and year to year, largely due to the variability in reservoir management that occurs in response to water availability.

In three of the four years, phosphorus loading to the reservoir was greatest during the spring runoff when the reservoir was being refilled. The exception was 1978 when higher than normal rainfall and runoff occurred during July, August, and September, resulting in a higher phosphorus loading in the summer and early fall.

Greatest outflow of phosphorus from the reservoir occurs during late winter drawdown when reservoir water is anaerobic

TABLE 7. MONTHLY INFLOW AND OUTFLOW AMOUNTS OF NITROGEN, PHOSPHORUS, BOD_5 AND WATER VALUES FOR THE BIG EAU PLEINE RESERVOIR 1975-1978 (METRIC TONS)

		Total Phosphorus		Reactive Phosphorus		Kjeldahl Nitrogen		NO_3 & NO_2 Nitrogen		NH_3 Nitrogen		5 Day BOD		Water Volume Hectometers^3	
		In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
1975	January	0.2	2.8	2.1	1.6	1.1	31.3	1.0	1.5	0.1	1.6	1.4	42.2	1.0	25.3
	February	0.1	0.7	0.1	0.5	0.8	7.3	1.0	0.5	0.2	1.9	1.5	7.3	0.9	5.6
	March	3.8	0.0	2.2	0.0	32.4	0.0	11.8	0.0	10.9	0.0	48.5	0.0	8.3	0.0
	April	34.4	2.2	23.0	1.5	156.3	24.0	91.9	6.5	51.0	11.3	289.0	40.4	102.4	17.5
	May	2.4	2.3	1.6	1.3	15.5	28.7	11.9	12.1	2.4	11.2	21.9	47.1	13.8	20.1
	June	3.3	0.5	2.2	0.4	18.3	7.5	3.4	2.1	2.3	2.2	21.9	12.8	10.6	6.8
	July	0.9	1.0	0.6	0.6	3.9	18.1	1.1	3.0	1.0	2.4	3.7	62.7	1.7	19.1
	August	1.1	1.7	0.8	0.4	5.8	33.0	2.6	1.5	1.8	1.8	10.7	93.6	6.2	21.4
	September	2.4	1.6	2.1	0.6	17.0	29.2	5.1	1.0	2.0	2.1	29.5	98.5	11.5	20.7
	October	0.4	2.4	0.2	0.7	3.1	40.2	0.8	2.6	0.5	3.8	4.2	69.0	2.0	28.1
	November	6.7	0.4	3.4	0.3	38.5	8.3	19.6	0.8	2.6	0.5	98.9	16.2	26.8	6.5
	December	7.7	0.6	5.4	0.5	20.4	13.8	18.7	2.4	4.2	1.6	118.4	14.2	19.3	8.6
	Total	63.4	16.2	41.7	8.4	312.2	241.4	168.9	34.2	79.0	40.4	650.1	504.0	204.5	179.7
1976	January	0.4	5.4	0.4	2.5	2.4	48.3	3.6	21.2	0.6	7.1	6.4	52.5	2.0	46.4
	February	1.5	10.5	0.9	5.1	14.7	49.2	7.0	37.0	4.8	26.9	12.2	84.2	4.9	44.9
	March	39.8	10.6	20.3	5.6	320.9	82.7	132.5	14.5	79.5	31.4	267.9	146.9	130.5	20.5
	April	5.9	18.2	3.9	5.6	96.8	141.7	45.2	15.6	22.3	26.2	87.5	201.8	69.5	97.7
	May	1.3	1.7	0.6	0.5	15.9	36.4	3.9	7.3	2.4	4.7	19.1	28.9	10.8	14.1
	June	.5	0.7	0.3	0.4	2.3	14.7	0.5	4.6	0.6	2.6	1.9	24.1	1.0	13.8
	July	1.7	2.5	0.3	0.8	4.2	41.4	1.5	2.9	1.7	3.7	1.8	122.2	0.7	27.5
	August	1.2	2.4	0.1	0.9	1.4	38.1	0.5	0.8	0.5	2.8	0.8	96.8	0.7	23.1
	September	0.1	1.5	0.1	0.5	0.8	26.9	0.3	0.6	0.2	1.2	1.2	68.8	0.5	12.7
	October	0.0	1.1	0.0	0.5	1.5	18.3	0.5	1.6	0.3	0.5	1.5	28.5	0.8	8.2
	November	0.1	0.9	0.1	0.6	0.5	13.9	0.2	1.3	0.1	2.8	1.6	19.0	0.6	10.2
	December	0.0	0.9	0.0	0.5	0.2	12.1	0.2	3.7	0.0	1.7	0.7	22.9	0.2	9.1
	Total	50.5	56.4	27.0	23.5	461.6	523.7	195.8	114.1	113.0	111.6	402.6	896.6	222.2	328.2
1977	January	0.0	2.0	0.0	1.3	0.0	30.7	0.0	8.0	0.0	7.1	0.1	33.7	0.1	16.8
	February	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.0	0.0	0.1	0.2	0.1	0.7	0.2
	March	6.0	0.0	4.8	0.0	49.5	0.0	25.5	0.0	8.3	0.0	44.7	0.0	27.0	0.1
	April	2.6	0.0	1.6	0.0	19.7	0.1	13.2	0.1	3.4	0.0	41.8	0.3	20.2	0.7
	May	0.3	1.4	0.2	0.4	2.1	10.7	0.3	5.4	0.3	5.7	3.5	29.3	3.0	10.6
	June	0.1	0.0	0.1	0.0	1.2	0.0	0.1	0.1	0.1	0.0	1.8	0.1	1.6	2.6
	July	1.3	0.6	1.1	0.3	10.0	6.3	0.9	0.0	1.0	0.5	2.7	16.9	8.5	6.2
	August	0.1	0.2	0.1	0.1	0.5	2.0	0.1	0.1	0.1	0.1	1.1	7.6	2.2	2.5
	September	4.0	0.0	2.5	0.0	30.0	0.0	2.7	0.0	1.9	0.0	27.8	0.0	18.9	1.2
	October	4.3	0.0	2.6	0.0	22.3	0.0	5.6	0.0	1.3	0.0	17.1	0.0	17.4	1.6
	November	4.2	0.0	3.1	0.0	18.3	0.3	13.5	0.0	1.4	0.0	25.9	0.4	19.6	4.3
	December	3.5	0.6	2.9	0.2	14.7	16.0	15.4	2.2	2.5	1.6	18.1	19.2	13.4	16.8
	Total	26.4	4.8	19.0	2.3	168.4	66.3	77.4	15.9	20.3	15.1	184.8	107.6	132.6	63.6
1978	January	0.6	2.5	0.5	1.7	2.3	46.7	3.7	8.0	0.5	7.8	4.1	36.8	2.7	44.9
	February	0.3	4.9	0.3	4.4	0.6	59.1	1.7	19.6	0.2	10.8	1.3	71.1	1.1	49.0
	March	14.6	7.8	7.9	5.0	156.3	59.1	56.1	31.5	62.9	11.5	1.1	90.3	57.2	41.2
	April	11.8	0.0	7.4	0.0	108.8	0.0	81.4	0.0	14.4	0.0	139.9	0.0	66.7	1.3
	May	5.8	1.1	3.3	0.3	30.9	20.8	8.6	12.8	1.4	2.4	55.2	19.5	23.2	19.9
	June	3.5	1.5	2.7	0.4	22.9	26.7	4.7	14.6	1.3	2.5	35.2	44.7	18.1	23.4
	July	18.4	15.2	15.1	2.8	97.7	237.4	36.8	11.7	3.2	7.2	138.9	802.7	80.7	108.5
	August	11.2	8.7	7.1	2.9	67.0	103.7	8.3	4.4	1.1	30.8	102.5	339.3	45.9	63.6
	September	13.0	4.4	7.5	2.0	23.9	36.7	11.3	2.1	4.7	9.2	67.7	160.7	45.6	39.9
	October	1.9	1.1	1.3	0.4	13.8	12.5	4.5	0.7	0.4	0.5	13.0	35.6	13.9	12.9
	November	1.2	1.3	0.4	0.4	4.1	13.9	4.1	0.2	0.1	0.1	4.4	30.8	10.8	14.8
	December	1.0	2.4	0.2	0.6	1.8	30.5	2.6	0.5	0.1	0.3	2.4	48.3	3.3	35.0
	Total	83.3	50.9	53.7	20.9	530.1	647.1	224.3	106.1	90.3	83.1	565.7	1697.8	369.2	454.4
	Total for 4 years	223.6	128.3	141.4	55.1	1462.3	1478.5	666.4	270.3	302.6	250.2	1803.2	3206.0	928.5	1025.9

and sediment resuspension is occurring and during spring runoff when water is rapidly moving through the reservoir. Other periods of high discharge result in significant loss of nutrients from the system, as occurred in the summer of 1978. Phosphorus retention in the reservoir averaged 43 percent for the 4-year period and ranged from plus 82 percent in 1977 to minus 12 percent in 1976. These data indicate a wide variation in year-to-year and month-to-month retention of phosphorus and indicate possibilities for minimizing phosphorus retention.

Since the largest phosphorus load usually enters the reservoir during spring runoff, if more of this water were allowed to flow through during reservoir drawdown, less phosphorus would settle out and be available for resuspension. This could only be accomplished when an excess of snow was avialable and only during the early thaw period which is the most nutrient rich. Accumulations of phosphorus in the deeper pools would contribute less to summer algae populations since the deep accumulations are less subject to resuspension during summer drawdown.

Allowing a flow-through condition to occur during other wet periods would also benefit the reservoir, as occurred in the summer and fall of 1978. During this time, there was high nutrient loading from heavy and frequent rains, but algae populations did not increase. This was most likely due to the high discharge rate from the full reservoir which allowed a faster than normal exchange of water, preventing buildup of large algae populations.

Reservoir drawdown aids transport of phosphorus and other nutrients out of the reservoir or to deeper pools within the reservoir through drawdown-related scouring. This process is beneficial only to the point where sediment resuspension has a negative effect on algae biomass or winter oxygen conditions. The annual drawdown cycle which transports nutrient-rich sediment from shallow water areas to deep pools or out of the system reduces the fertility of the sediments in the shallow areas which could be a definite benefit if and when conservation practices reduce nutrient loading to the reservoir. Less nutrient load would then be deposited in shallow areas during spring runoff and reservoir refilling resulting in less resuspension during summer drawdown.

Nutrient budget data for nitrogen indicate a pattern similar to phosphorus. Highest loading of all forms of nitrogen occurs during spring runoff while outflow occurs during drawdown conditions or whenever high flow is routed through the reservoir, as during spring runoff in 1976 or summer conditions in 1978. Retention of nitrogen within the reservoir is complicated by large blooms of the nitrogen-fixing alga, Aphanizo-

menon flos-aquae. For the four-year period, total nitrogen retention within the reservoir was only 17.8% compared to 43 percent for phosphorus. The weight-weight nitrogen to phosphorus ratio of the inflow averaged 9.5 while that of A. flos-aquae was 83.4 (Sullivan 1978). This would indicate that sedimentation of that alga would result in a much higher retention of nitrogen than phosphorus, but the opposite trend was observed. These data, therefore, indicate a very significant net input of nitrogen to the reservoir through nitrogen fixation. The wide nitrogen-phosphorus ratio found for algae cells also indicates that phosphorus is limiting algae growth in this reservoir (Sullivan 1978).

The inflow data for BOD_5 show a pattern similar to nitrogen or phosphorus with the heaviest loading during major runoff events, especially in early spring. Outflow BOD_5 differs from other parameters as it is by far the highest during summer months due to outflow of algae biomass. The outflow of BOD_5 for the 4-year period is double the inflow. High outflow of BOD_5 also occurred during winter drawdown events when sediment was resuspended and during spring runoff when water was routed quickly through the reservoir, as in 1976. BOD loading to the reservoir during minimum flow is very low; this further indicates the lack of point source impacts.

These nutrient and BOD data show that the nutrient loading to the reservoir is due to runoff from agricultural lands which primarily occurs during spring and any unusually high rainfall periods in the summer and fall. Reservoir management has a significant effect on the movement and retention of nutrients and BOD within the reservoir. These data could be used to design a management strategy that would minimize negative impacts and maximize nutrient discharge from the reservoir.

RESERVOIR STUDIES

Various studies were conducted on the Big Eau Pleine Reservoir in an attempt to quantify the conditions leading to the large summer algae blooms and winter fish kills. Once the sources of the problems are identified and quantified, management recommendations can be made to help provde solutions.

The following studies were undertaken to quantify various aspects of reservoir nutrient and algae dynamics and oxygen consumption processes. Initially all were designed to provide both quantitative data on various aspects of the reservoir and input data for a limnological model. Considerable effort was expended in attempting to use a model to describe the problems; however, use of the model was discontinued due to its inability

to simulate a mass balance of dissolved solutes during reservoir drawdown.

Detailed results of the reservoir studies are found in the following Masters theses: Primary Production of the Big Eau Pleine Reservoir, Wisconsin, Sullivan 1978; Long-Term BOD Analysis of the Big Eau Pleine Reservoir, Wisconsin As Related to BOD Source, Swalby 1979; Computer Modeling Snow Relationships in the Big Eau Pleine Watershed, Wisconsin, Marano 1979; Sediment Relationships in the Big Eau Pleine Reservoir, Hammermeister 1981; Computer Models, Water and Nutrient Budget for the Big Eau Pleine Reservoir, Vennie 1981.

The following material summarizes the major findings of these projects plus other supporting data generated by this study.

Primary Production in the Big Eau Pleine Reservoir

Primary production in the Big Eau Pleine Reservoir has been recognized as excessive, and the reservoir has been classified as highly eutrophic (USEPA 1975, Bartelt et al. 1973).

The results of 14C primary production studies, chlorophyll analysis, and plankton counts and identification carried out by Sullivan (1978) are presented in Figures 6, 7 and 8. These data support earlier studies, indicating that the reservoir is hypereutrophic with the summer phytoplankton dominated by Aphanizomenon flos-aquae. The annual primary production for 1975 and 1976 was 340 and 685 g C/m^2, respectively; chlorophyll a during the summer (June-September) was 52.2 ug/l and 103 ug/l, respectively. Results of nutrient enrichment bioassays and the chemical composition of A. flos-aquae indicated that phosphorus was the primary limiting nutrient during 1975 and 1976 summer months (Sullivan 1978).

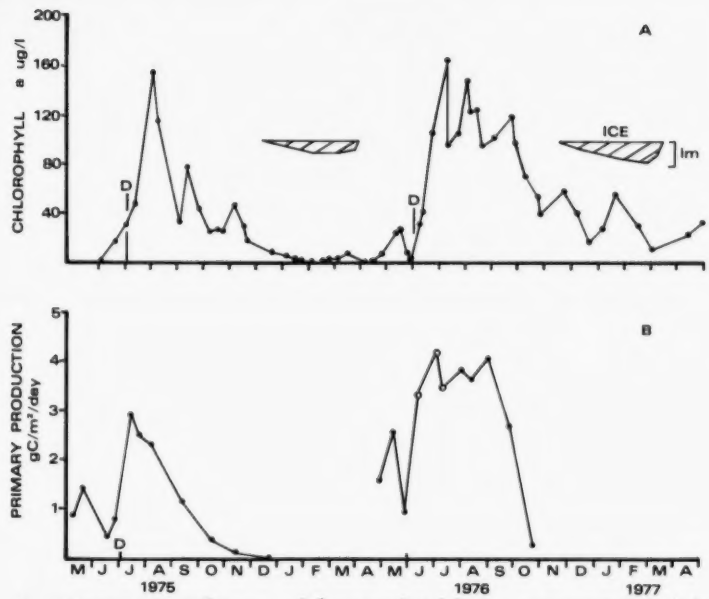

Figure 6. A. Mean surface chlorophyll a concentration for the Big Eau Pleine Reservoir. The letter D indicates the onset of reservoir drawdown. B. Carbon-14 primary production at site 14. The (δ) denotes carbon-14 production estimated from the oxygen technique using a regression equation.

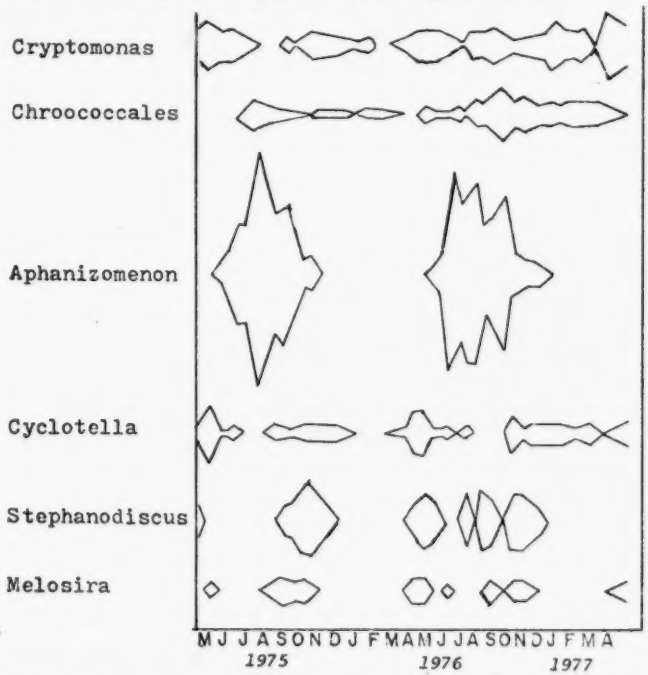

Figure 7. Relative change in the dominant phytoplankton taxa volumes at site 14 (Sullivan 1978).

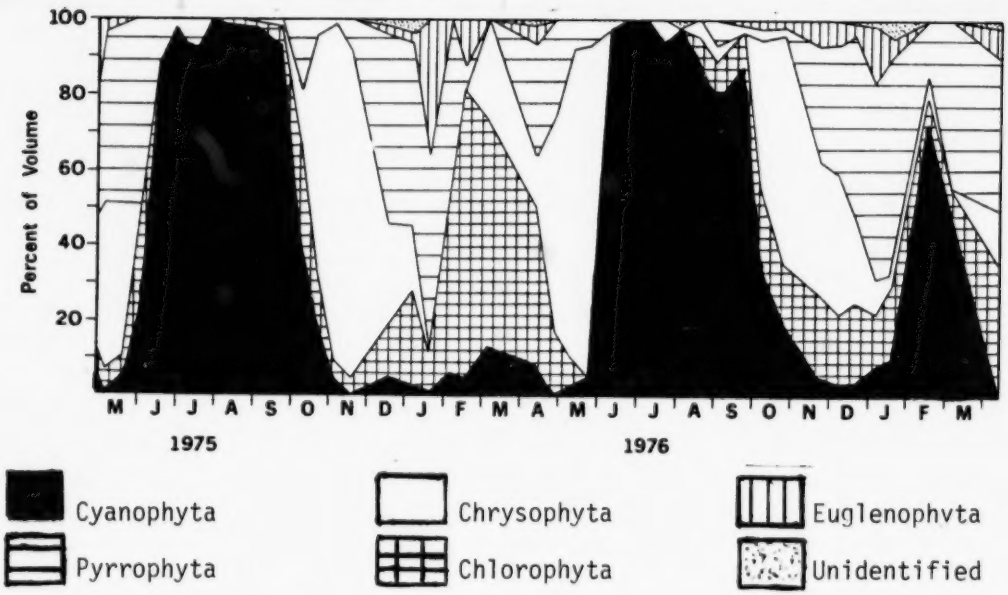

Figure 8. Percent composition of indigenous phytoplankton in the Big Eau Pleine Reservoir (Average of all surface samples).

Chlorophyll a and Secchi disc values for 1975 through 1978 show a large yearly variation in the Big Eau Pleine Reservoir (Figure 9). These data clearly illustrate the variability of primary production in a reservoir that undergoes wide variations in nutrient loading and wide fluctuations in water level. These conditions are not typical of many lake systems and, therefore, do not fit sample models designed to predict lake response to nutrient loading.

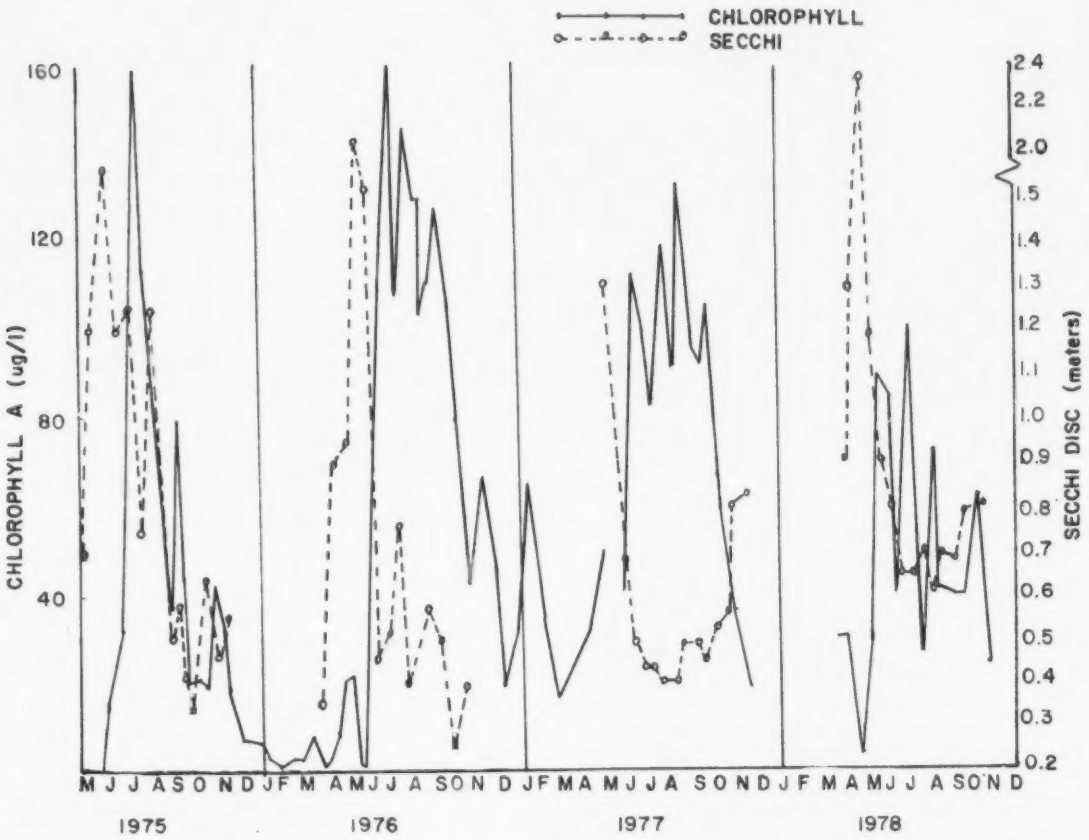

Figure 9. Chlorophyll and Secchi disc values for the Big Eau Pleine Reservoir 1975-1978.

One factor that is very significant in this reservoir that is not commonly discussed in eutrophication studies is the effect of reservoir drawdown on phosphorus levels and subsequent phytoplankton production. Figure 10 compares reservoir volume to total phosphorus values for the reservoir from 1974 through 1978. Total phosphorus levels are highest early in the spring (Figure 10); however, it can be seen that concentrations decrease rapidly shortly after the reservoir refills in the spring. Total phosphorus concentrations increase again early in the summer, corresponding closely to the initiation of reservoir drawdown, and remain high throughout the summer months. Inflow concentration and loading is usually low during this period, pointing to sediments as the only obvious source of phosphorus.

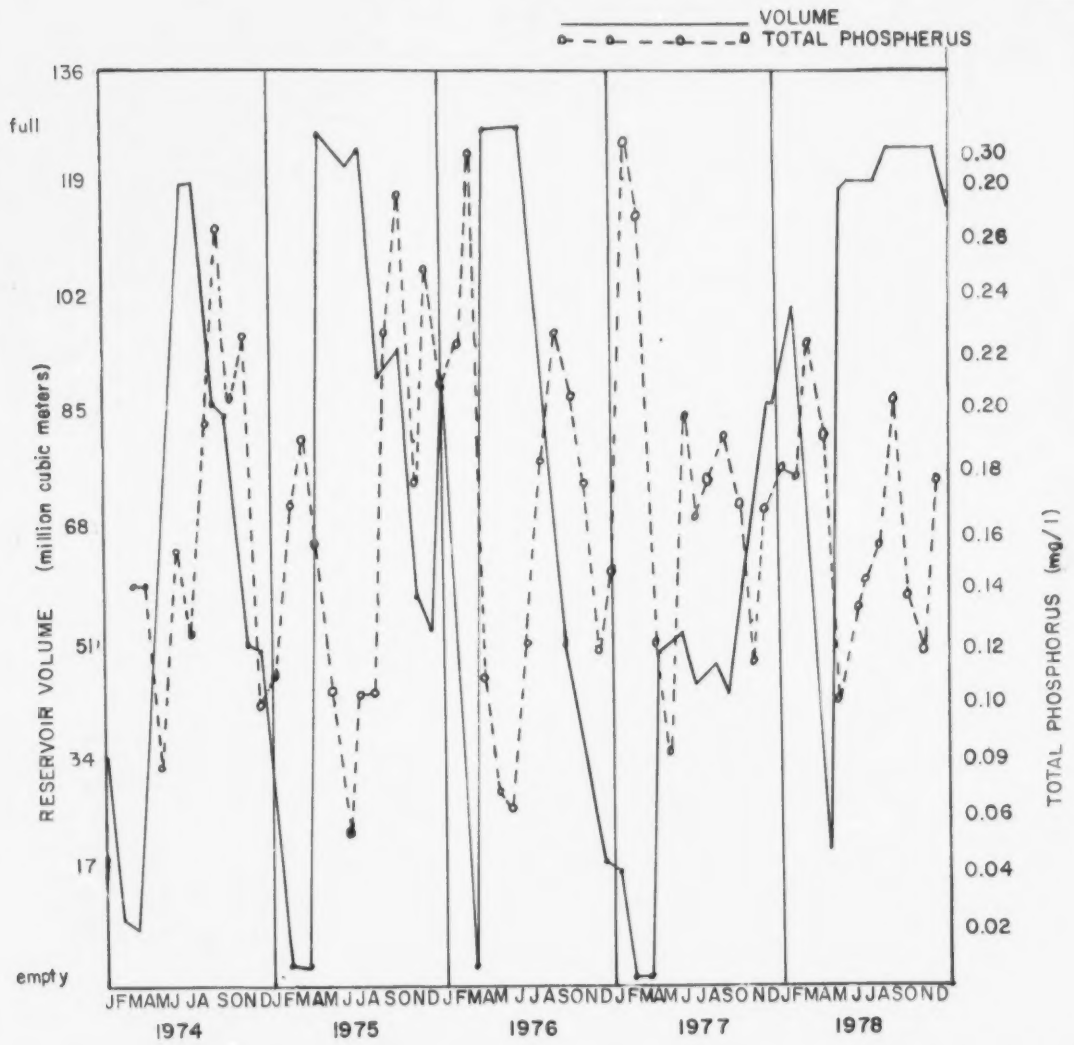

Figure 10. Reservoir volume and total phosphorus concentrations for the Big Eau Pleine Reservoir 1974-1978.

This increase in phosphorus during the summer seems reasonable for a reservoir of this type as it is filled during spring runoff with nutrient-rich water which disperses over the entire reservoir. Much of the nutrient load settles out and is relatively easily resuspended later in the summer by wave action. Summer drawdown provides the mechanism by which wave action can progressively affect deeper sediments. A limited amount of anaerobic phosphorus release also occurs, especially

early in the summer when water depths are great enough to allow thermal stratification.

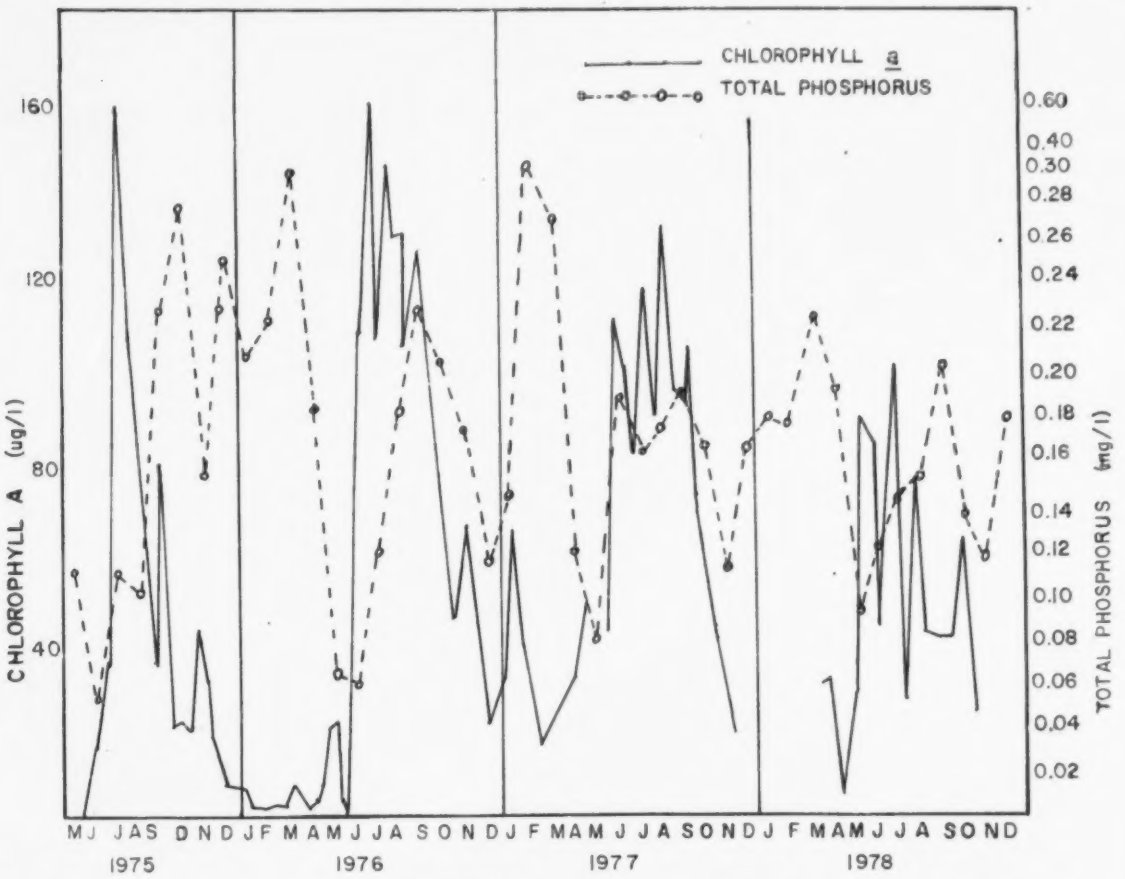

Figure 11. Chlorophyll a and total phosphorus for the Big Eau Pleine Reservoir 1975-1978.

Figure 9 tends to indicate a gradual improvement in water quality, especially from 1976 to 1978, as chlorophyll levels gradually decreased and Secchi disc values increased. However, yearly nutrient loading data do not indicate an improvement in water quality (Table 8). This points out that factors other than annual phosphorus loading must be considered, such as seasonal phosphorus loading, internal phosphorus loading, year-to-year differences in solar radiation, and retention time which all have an effect on summer chlorophyll production. The difference in solar radiation between 1975 and 1976 is discussed by Sullivan (1978).

TABLE 8. YEARLY AND SEASONAL TOTAL PHOSPHORUS LOADING, SUMMER DRAWDOWN, AND AVERAGE CHLOROPHYLL A VALUES FOR THE BIG EAU PLEINE RESERVOIR.

	Total P Inflow (Metric Tons)			Meters Summer Drawdown	Average Chlorophyll a (mg/l)
	Yearly	Jan. 1-July 1	June 1-Sept. 1	June 1-Sept. 1	July-August
1975	63.4	44.2	5.3	1.31	104
1976	50.4	48.9	1.4	2.53	126
1977	26.4	9.0	1.5	0.61	105
1978	83.3	36.6	33.1	0.0	65

The interrelationship between seasonal phosphorus loading, summer drawdown and chlorophyll a can better be seen in Table 8. Yearly total phosphorus loading was highest in 1978 during which average chlorophyll a was lowest for the 4-year period. Summer drawdown did not occur in 1978 due to a wetter than normal summer, which resulted in high river flows and nutrient loading throughout the entire summer. Retention time was also relatively short during this period. Data for 1977, with the lowest yearly and summer phosphorus loading, still show very high levels of chlorophyll a. Water levels during this period were much lower than other years due to a lack of spring recharge, and a drawdown did occur during the summer months. From these data, there obviously is no clear relationship between reservoir total phosphorus loading from external sources and chlorophyll a; however, Figure 11 shows a much better relationship between reservoir total phosphorus concentrations and chlorophyll a values. This reemphasizes the importance of considering internal nutrient loading as a major factor affecting primary production. The above data do indicate that summer drawdown is a major factor promotiong internal phosphorus loading and subsequent algae blooms (Figure 6).

Reduced nutrient loading from watershed sources could be expected to result in an improvement in reservoir quality over a several-year period. This may actually occur faster in a reservoir such as the Big Eau Pleine than in lakes, due to drawdown-related scouring which helps in removing accumulations of nutrient-rich sediments or, at least, transporting them to deep water areas where they are less likely to become resuspended during the summer months.

Reservoir Oxygen Relationships

Most people consider winter oxygen depletion as the major problem in the Big Eau Pleine Reservoir. The highly eutrophic nature of the reservoir results in rapid growth of fish and an excellent fishery whenever over-winter survival occurs (Kaster 1976). Two projects were oriented toward the oxygen depletion problem in the reservoir, both were designed to evaluate reservoir and inflow water quality relationships and to provide needed information for the water quality model.

Long-Term BOD

Long-term BOD studies were conducted on inflow and reservoir samples throughout 1975 and 1976 to characterize the oxygen demand of allochthonous and autochthonous organic material. A major emphasis of this research was to determine the amount of oxygen demand due to phytoplankton production. The total inflow and outflow data presented in Table 7 indicate a large outflow of BOD material during summer months and a major inflow during spring runoff. Figure 12 shows the correlation achieved between BOD_{20} and summer chlorophyll values for the Big Eau Pleine Reservoir (Swalby 1979).

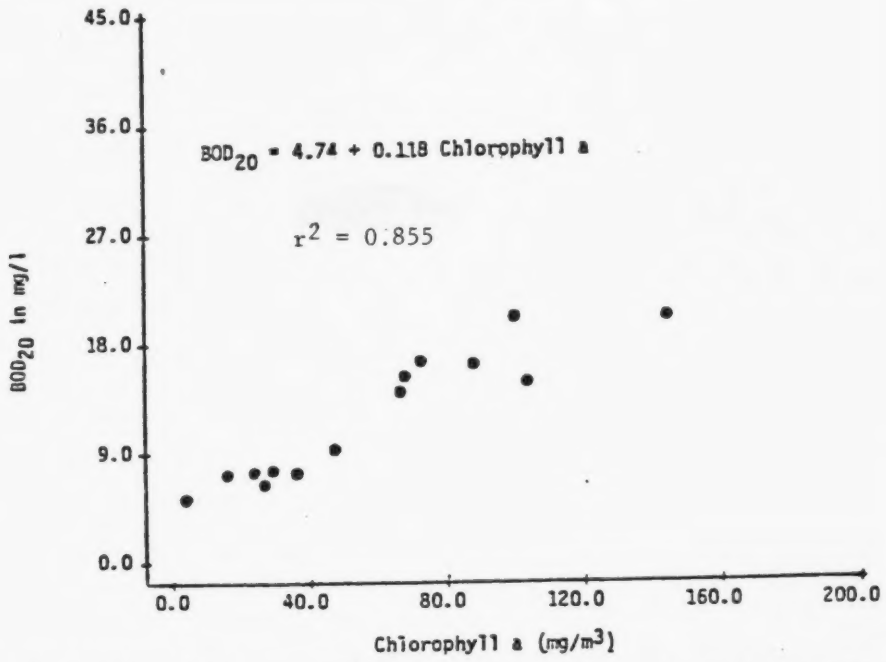

Figure 12. Relationship of summer surface BOD_{20} to chlorophyll *a* and biomass in the Big Eau Pleine Reservoir.

The BOD to chlorophyll relationship resulted in the follow-int regression equations for the Big Eau Pleine Reservoir.

BOD_5 = 1.52 + 0.050 chlorophyll a (mg/m^3) r = 0.928*

BOD_{20} = 4.74 + 0.118 chlorophyll a (mg/m^3) r = 0.925*

BOD_{50} = 8.37 = 0.150 chlorophyll a (mg/m^3) r = 0.960*

*Sign·ficant at 0.01 level.

Figure 13 shows the BOD_5 distribution in the reservoir for 1976, indicating three peaks due to (1) winter drawdown, (2) spring runoff, and (3) summer phytoplankton.

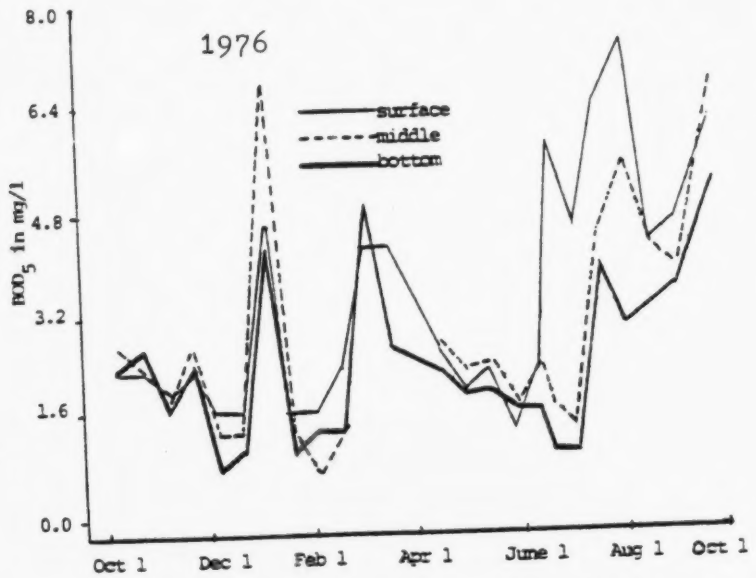

Figure 13. Top, middle, and bottom depth BOD_5 values for the Big Eau Pleine Reservoir through water year 1976. Each point represents an average of values obtained at 3 to 8 reservoir sites.

Using standard BOD_5 data to estimate oxygen depletion in a reservoir system can be misleading. This is due to variability in amount and decomposition rates of BOD material, whether from non-point source runoff or phytoplankton production. Oxygen demand often continues for up to 100 days at 20°C, which suggests that BOD produced in summer or fall by phytoplankton could affect the reservoir during the winter. Figure 14 shows the typical long-term BOD curves where the predominant source of BOD is decomposing phytoplankton.

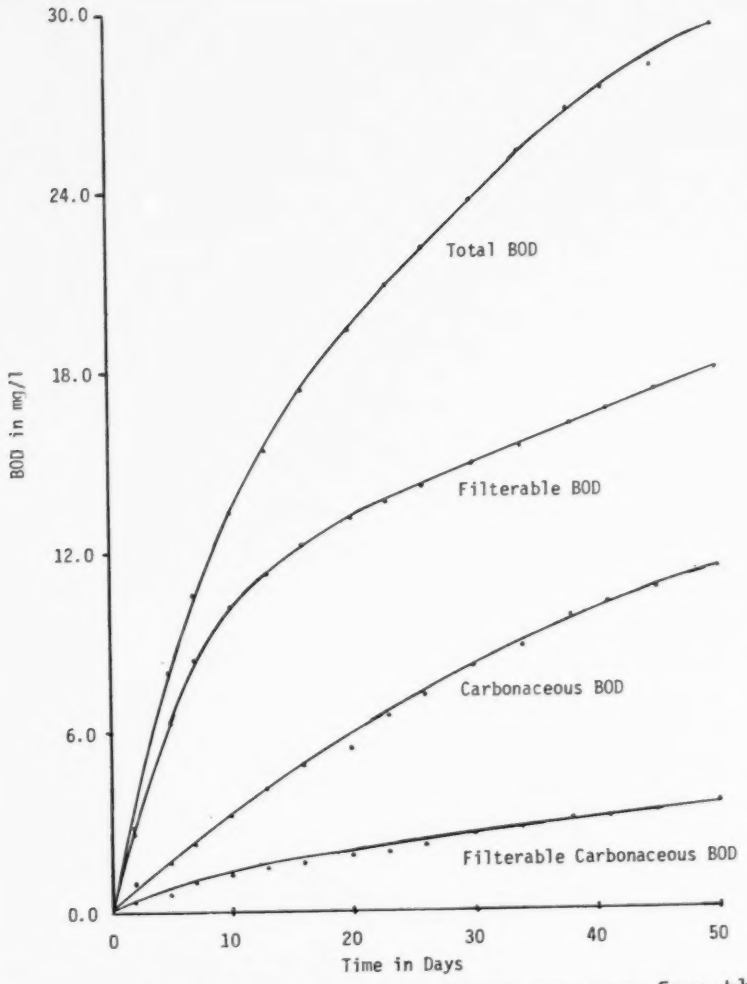

Figure 14. Total and carbonaceous BOD curves for the Big Eau Pleine Reservoir during an algae bloom.

One approach that has been used successfully to account for long-term BOD effects in computer models has been to separate the BOD curve into there separate sub-curves, each having a unique reaction rate (Patterson et al. 1975). Each portion of the curve is assigned a portion of the total BOD (L_1, L_2, L_3) and a rate constant for that portion of the curve, K_1, K_2, K_3. The BOD equation then becomes:

$$Y_t = L_1 (1-e^{-K_1 t}) + L_2 (1-e^{-K_2 t}) + L_3 (1-e^{-K_3 t})$$

where Y_t = Total BOD and t = time.

This approach was used to characterize long-term BOD data from the Big Eau Pleine Reservoir (Table 9). The long-term BOD values for summer and fall indicate that BOD could ultimately consume all the available oxygen. However, this is misleading since reaction rates are greatly slowed under winter conditions. Long-term BOD's were done at 20° and 4° to calculate a theta (0) value for correlating the reaction rate for temperature ($K_t = K_{20}\ e^{t-20}$). These data indicate that the theta value for the Big Eau Pleine River and Reservoir is 1.073 which means the $20°BOD_{50}$ values should be multiplied by 0.324 to get values for 4°C. This value is similar to that found by Schroepfer et al. (1964) and Zanoni (1970). Under ice cover reservoir temperatures average closer to 1°C which would reduce the rate further. Therefore, it is very unlikely that BOD produced by algae in the summer or fall would totally deplete the oxygen in the reservoir at freeze-up unless a large bloom occurs just prior to freeze-up, and the freeze-up occurs early and lasts longer than normal. This lack of total oxygen depletion by BOD is borne out by surface oxygen values in the reservoir prior to significant winter drawdown, as occurred in 1978 (Figures 15 and 16).

TABLE 9. AVERAGE SEASONAL BOD_{50} VALUES AND MATHEMATICAL COEFFICIENTS FOR THE BIG EAU PLEINE RESERVOIR SURFACE SAMPLES.

Season	BOD Fraction	N	Average BOD_{50}	K_1	K_2	K_3	L_1	L_2	L_3
Spring	Total	16	15.8	.054	.046	.0078	5.92	5.72	15.26
	Carbonaceous	16	12.9	.044	.041	.0055	5.32	4.25	14.75
Summer	Total	12	17.8	.087	.048	.0066	4.32	6.86	20.69
	Carbonaceous	12	12.5	.090	.043	.0063	3.83	5.21	15.50
Fall	Total	15	15.7	.057	.048	.0075	7.27	3.70	17.32
	Carbonaceous	5	8.5	.041	.053	.0037	5.57	2.37	8.79
Winter	Total	29	10.7	.054	.050	.0075	3.65	3.54	12.0
	Carbonaceous	17	7.5	.065	.046	.0065	2.60	2.36	8.80

Sediment Oxygen Demand

Another oxygen consuming process investigated in the Big Eau Pleine Reservoir was sediment oxygen demand (SOD). Sediment oxygen demand rates were determined at various sites representative of reservoir sediments during summer and winter

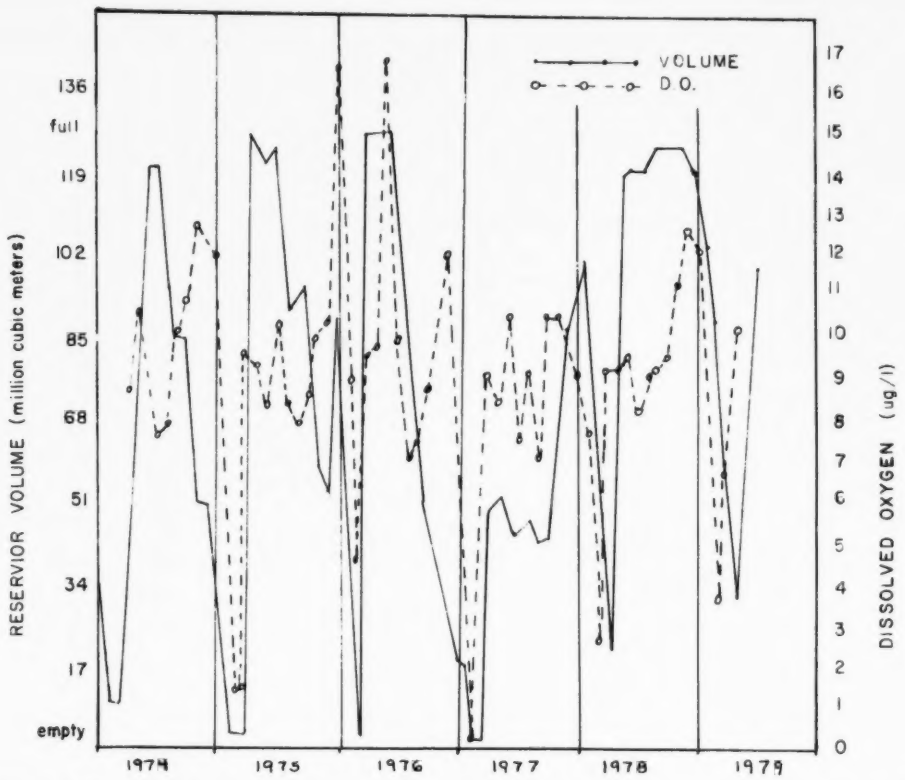

Figure 15. Reservoir volume and dissolved oxygen for surface samples 1974-1979.

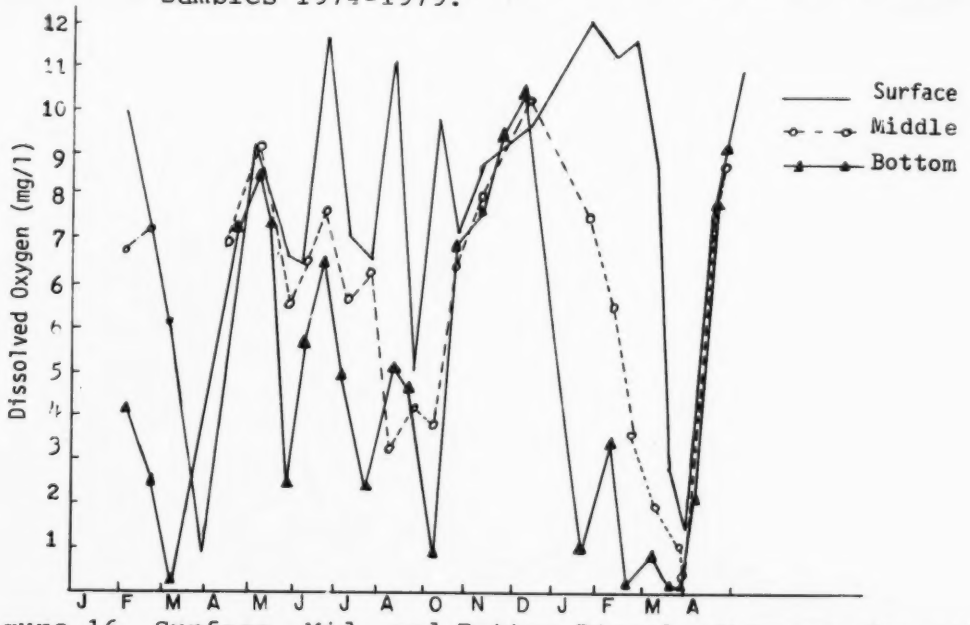

Figure 16 Surface, Mid, and Bottom Dissolved Oxygen for site 14 during 1978.

months using an in situ device. Core samples were also collected and tested in the laboratory at various temperatures to obtain SOD rates under various temperature conditions and over several seasons (Hammermeister 1980). Figures 18 and 19 present a summary of these data.

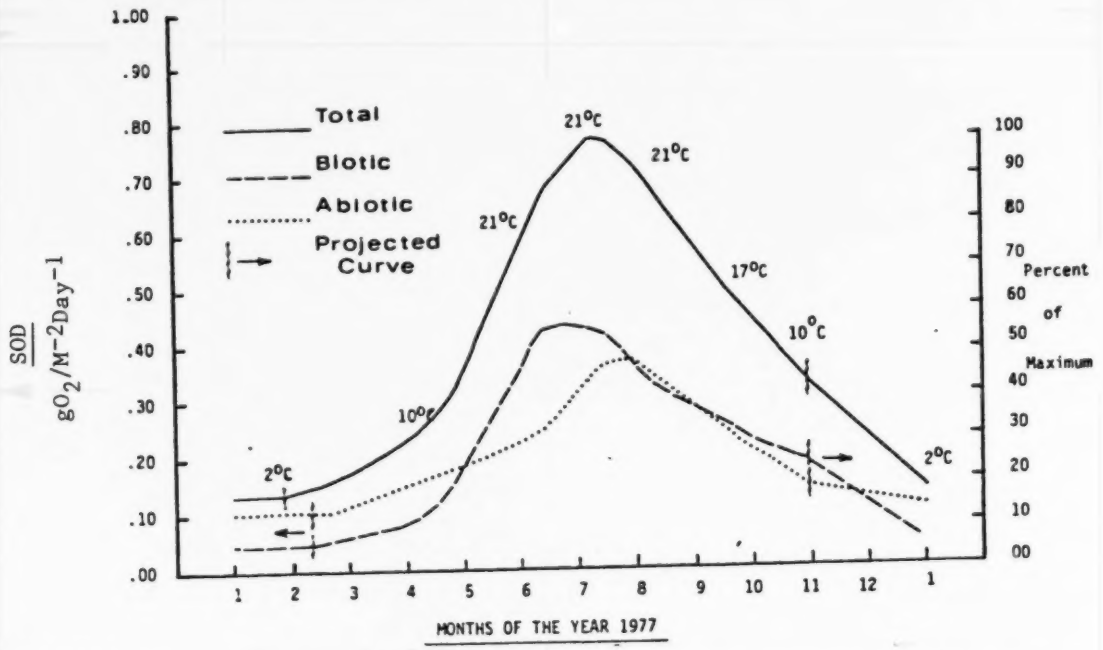

Figure 17. Average biotic and abiotic core SOD of sites 13 & 23 during 1977.

The SOD in the majority of the Big Eau Pleine Reservoir is moderate compared to other organically enriched sediments but is great enough to result in oxygen depletion near the bottom of the reservoir during the summer and winter. Bottom and top dissolved oxygen for the Big Eau Pleine Reservoir are shown in Figure 16. The rate of summer and early winter oxygen depletion at the bottom can be considered due largely to SOD.

The impact of SOD on oxygen values can be estimated by assuming a SOD value of 0.15 g^0/m^2/day SOD for the winter period and assuming complete mixing of water in the lower meter. With these assumptions, it is calculated that 67 days would be required to use up 10 mg/l oxygen. This would be comparable to a BOD_{67} of 10 mg/l at 2°C or about 30 mg/l BOD at 20°C. From these data, it is obvious that SOD in the near-bottom water is more important than BOD in consuming oxygen. Summer SOD rates are 4 to 5 times as great as during winter and result in fairly rapid deoxygenation of bottom water (Figures 16 and 17). The

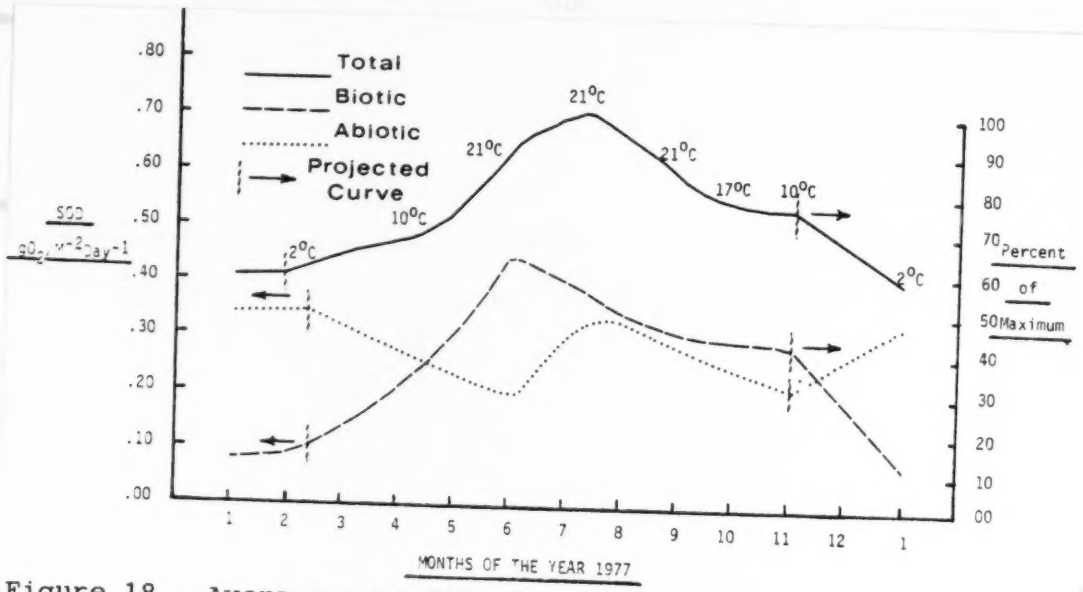

Figure 18. Average core SOD of sites 13 & 23 during 1977 (temperature corrected to 20°C.

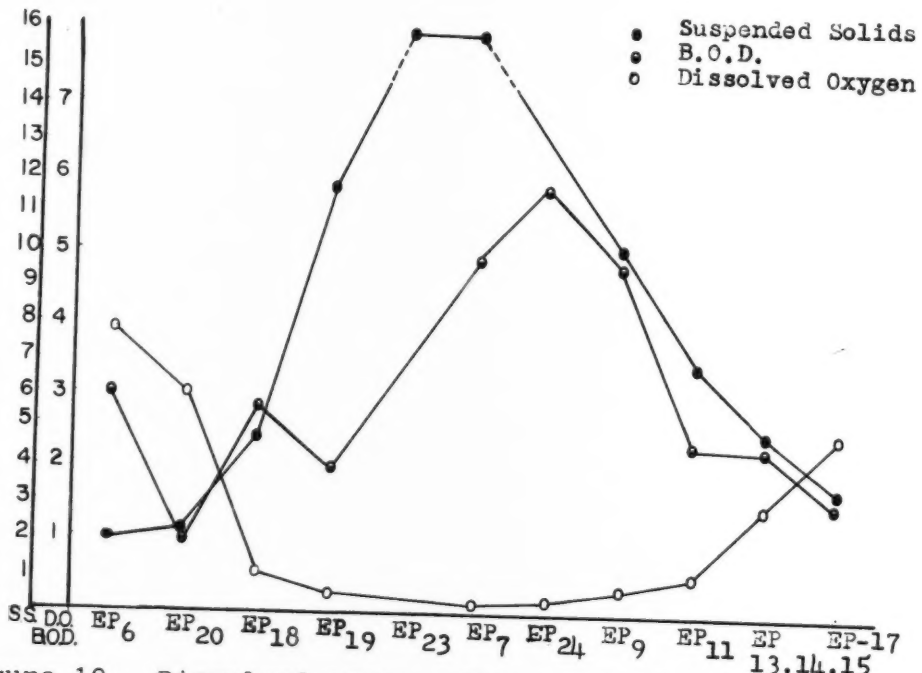

Figure 19. Dissolved oxygen, BOD_5, and suspended solids in the Big Eau Pleine Reservoir on 1-18-77 during a winter drawdown period.

higher summer SOD (Figure 17) is due to both temperature effects and organic wastes carried into the reservoir during spring runoff as shown by the BOD loading (Table 7) and organic production by phytoplankton in the reservoir. This fresh organic material has a high initial oxygen consumption rate which decreases over time as does a BOD sample.

SOD and BOD are significant factors in depleting winter oxygen in the reservoir but would not result in complete deoxygenation of the reservoir during a normal winter period. This assumption is supported by the winter BOD values and rate constraints and SOD rates and is shown by winter oxygen levels in surface samples prior to significant drawdown (Figures 15 and 16). The year 1978 is chosen to demonstrate this relationship; drawdown was delayed and snow cover was sufficient to prevent any significant oxygen replenishment by photosynthesis. One process that does occur in this reservoir that results in total oxygen consumption during late winter is sediment scouring resulting from reservoir drawdown. As drawdown progresses, it eventually lowers water levels in the upper reservoir areas to the point that all flow is returned to the old river channel. Organic material deposited during runoff events and from summer phytoplankton production is then resuspended along with reduced chemical components from anaerobic sediments. This material quickly combines with any remaining oxygen in water it contacts. This process gradually moves down through the reservoir as drawdown progresses, resulting in extensive fish kills. Figure 19 shows the conditions on January 18, 1977, during such an event.

EVALUATION OF MODELS

Advantages and disadvantages of models used are:

USDAHL-74 Hydrology Model

Advantages: It is an excellent hydrology model for use during summer months when sufficient data are available for calibration.

Disadvantages: The snowmelt routine needs significant refinement as it is not sensitive enough to simulate snowmelt and spring rain events in northern climates.

ERODE

Advantages: 1. Basically, it is an excellent model and allows researchers to work with specific runoff events which is generally a better approach to studying soil erosion than using long term erosion predictions. 2. The revisions made during this project make it more useful with data from watersheds having diversified land use.

Disadvantages: The model should be coupled to a hydrology model. Modifications in land-use practices will often affect water movement as well as sediment transport. Therefore, the effect of conservation practices can best be gauged by simultaneously studying both hydrologic and soil transport processes.

There is a need to improve both hydrology and erosion models so that they are sensitive to effects resulting from a variety of soil and water conservation practices. Some of these practices can be simulated by the existing models, others cannot. The biggest weakness appears to be in the lack of sensitivity to soil differences resulting from land uses such as grazing, cultivation, or vegetation-cover effects on water infiltration and soil permeability.

Limnologic Models

The limnologic models used in this project generally were found to be inadequate to simulate processes occurring in the Big Eau Pleine Reservoir.

Advantages: 1. Basic limnological processes are well developed for use in lakes and reservoirs over relatively short time periods. 2. The relative importance of the numerous factors that affect phytoplankton production can be evaluated by the use of these models during summer months as long as water levels do not vary greatly and the phytoplankton assemblage does not change significantly.

Disadvantages: 1. The model cannot simulate a solute mass balance during reservoir drawdown. 2. Simulations over long time spans require many model coefficients to be changed as phytoplankton specification changes. 3. The large loss of inflowing phosphorus during the early spring period cannot be accounted for by the model. 4. Sediment resuspension processes occurring in a reservoir cannot be simulated by the model. Further refinement in modeling sediment-water interrelationships is needed.

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